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INDEPENDENT STRATEGIC ANALYSIS OF AUSTRALIA'S GLOBAL INTERESTS

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Research and Development in the Global Desalination Industry

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Key Points

- As global demand for freshwater continues to rise, there is an increased need to identify new sources of water to bolster supply.
- Desalination is one such method, particularly in arid and semi-arid parts of the world where other water supply options are limited.
- The energy intensity, cost and environmental effects of desalination remain key concerns globally, but research and development efforts are being made on each of those fronts.
- Despite some problems with Australian desalination facilities, on the whole the industry has helped to ensure that major population centres retain a high degree of climate-independent water security.

Summary

Desalination is becoming an increasingly common way of increasing water supplies in the face of rising demand. The wider adoption of this technology is impeded by: the energy-intensive nature of water desalination, the high costs associated with the construction and ongoing maintenance of desalination plants and the effect by-products could have on the natural environment. Research and development efforts have concentrated on improving the materials used in desalination plants, as well as the process of desalination itself. While the widespread commercial application of those investigations is unlikely to occur within the next decade, it bodes well for the future of desalination as a source of freshwater.

Analysis

Desalination is an increasingly common method of improving water security in arid and semi-arid regions. A decade ago, there were slightly more than 13,000 desalination plants in operation globally. Together they provided 0.5 per cent of the world's water. According to the International Desalination Association, the 19,000 desalination plants that now operate globally each day produce 88.6 gigalitres of water. The water from those facilities supports 300 million people. Today about one per cent of the world's freshwater is sourced from desalination facilities.

Desalination plants are usually located in coastal areas, as they draw water from oceans or seas, but smaller plants operate in inland areas to remove impurities from brackish water sourced from rivers or aquifers. As close to 40 per cent of the global population lives within 100 kilometres of an ocean or sea, desalination could play a large role in ensuring future global water security.

The energy intensity, cost and potential environmental effects of desalination are the main problems with the technology. In total, the world's desalination plants consume about 200 million kilowatt hours of electricity per day, with energy costs accounting for about half of the total operation and maintenance costs. A typical plant consumes between two and five kilowatt hours of electricity to produce one kilolitre of freshwater. Energy costs have declined significantly since the 1980s, when big municipal desalination plants began operating. The first plant, which began operating in Saudi Arabia in 1980, consumed more than eight kilowatt hours of electricity per kilolitre of freshwater. The cost of desalination has continued to decline significantly over the past decade; in some locations it is as much as 20 per cent cheaper than in 2010. Brine, which is often twice as saline as seawater, is usually pumped into the ocean to mix with the seawater. The environmental effect of brine discharge remains a major concern worldwide, but many plants are beginning to deploy diffusers that increase the volume of seawater mixing with the brine, to prevent spots of high salt concentration. Some desalination companies are also exploring "zero liquid discharge" options that aim to remove all of the water from brine, to leave only dry salt. It remains unclear, however, how that salt will be disposed of.

While desalination is an energy-intensive process and is therefore a relatively expensive way to produce freshwater, it has the benefit of being climate-independent. Any effort that makes the process more efficient and limits the environmental effects will pay large dividends.

Reverse Osmosis

Since the introduction of reverse osmosis (RO) technology in the 1960s, the energy requirements of desalination plants have declined. Older technologies boiled seawater to turn it into steam, before it was re-condensed into drinkable water. Some of those older plants are still in use, mainly in the Middle East.

RO is the most common desalination technology currently in use globally. RO plants use electrical pumps to force water through a membrane, rather than using thermal energy to heat water; making them more energy-efficient. Membranes have a relatively short lifespan, however, depending on the quality and pre-treatment of the feedwater. They must be replaced often, adding an ongoing cost to RO plants that thermal plants avoid.

The most advanced RO plants purify water using a four-stage process. During the first filtration stage, water is drawn through a series of increasingly fine filters to remove large pieces of debris and sediment. It then moves through fine polypropylene hollow fibres to remove suspended solids, bacteria and some viruses. In the third stage, the water is forced, under high pressure, through layers of semi-permeable membranes that remove almost everything except water molecules. After that stage, the water is so pure that minerals are re-added. In the final stage, the water is exposed to ultraviolet light and dosed with antiseptic agents, to ensure that no trace elements have made it through the membrane.

About half of the energy consumed by an RO desalination plant is used in pushing water through a membrane (the third stage of the process). Most research and development efforts that focus on reducing energy consumption, have sought to improve those membranes. Conventional membranes are made of a polyamide (a tangle of artificially produced fibres) and require constant maintenance, as they can easily become clogged during normal operation.

Graphene could be used to make more efficient membranes that are thinner, stronger and more porous than existing polyamide ones. While the technology is still in the testing phase, early indications suggest that pushing water through graphene membranes requires 15 per cent less energy for seawater and up to 50 per cent less for brackish water.

Lockheed Martin claims to have developed and tested the thinnest graphene membrane that can possibly be manufactured. Its Perforene membrane is made from a sheet of graphene that is one atom thick and contains holes that are one nanometre (one-billionth of a metre) in diameter. Lockheed Martin claims that because the membrane is so thin it requires less pressure, and therefore less energy, to filter water. The company also claims that Perforene membranes use ten to 20 per cent less energy than other membranes.

It is difficult to produce single-layer graphene on an industrial scale; the process is costly and often requires the use of explosive gases. Australian scientists have recently identified a way to produce graphene from soybean oil; a method that is cheaper and does not require the use of volatile substances. Similar discoveries, if they prove to be commercially viable, could further reduce costs in the future.

Other emerging nanomaterials, such as cellulose nanofibres (CNFs), could have both water treatment and filtration applications. As CNFs are derived from plants, they are a renewable material that is also biodegradable. They are also cheaper to produce than graphene-based products, but are less robust. As CNFs are currently used to strengthen plastics, they could be used to reinforce conventional membranes.

It will be some time before alternative membrane technologies are widely used in the desalination industry. Many are still in the research phase of the design process and remain too expensive for commercial use. Ongoing efforts to develop a membrane that conserves energy bode well for the industry, however, as they indicate that manufacturers are determined to make the technology more attractive to customers.

Forward Osmosis

Forward osmosis (FO) could also reduce the amount of energy required to desalinate water. Instead of forcing highly pressurised water through a membrane, the FO process allows water to naturally move through a semi-permeable membrane, moving from concentrated to less concentrated solutions.

FO plants have been trialled and built in Gibraltar and Oman. In 2011, a UK-based company, Modern Water, was awarded a contract to build the world's first FO desalination plant. It claims that its FO technology reduces energy costs by up to 30 per cent compared to RO technology, because the water does not need to be highly pressurised. Seawater in the Middle East is generally more saline than elsewhere and contains higher concentrations of algae and other suspended solids. As a result of those impurities RO membranes become fouled more frequently, increasing the cost of desalination. As Modern Water uses its FO plant to pre-treat water before it goes through an RO plant, it claims that the membranes need to be chemically cleaned less frequently, because membrane fouling is 'virtually non-existent.'

A study conducted by the Massachusetts Institute of Technology, however, argues that those claims are misleading. It suggests that FO is less energy-efficient than RO, because it involves two osmotic steps instead of one. The process begins with two mixtures of water, one for each side of the membrane. The water to be purified (the feed solution) goes on one side and a higher salinity draw solution goes on the other. The draw solution "pulls" water across the membrane through osmosis, until the salinity of the two solutions reaches equilibrium. The draw solution is then heated to remove the salt. If the desalination plant is co-located with a power plant or other thermal industrial facility, it can utilise the waste heat from that facility to save on thermal energy costs and, potentially, make the process cheaper than RO.

While efforts are being made to find ways to make FO more efficient for seawater desalination, outside of the Middle East it remains better suited to purifying extremely polluted water that cannot be treated using RO facilities, such as wastewater from the oil and gas industry. The wastewater from that industry can often be more saline than seawater and requires higher pressures for treatment with RO membranes. The required pressure is often so high that the membranes tear, leaving thermal evaporation as the only option to purify the water before releasing it into the environment. As that process uses 25 to 50 per cent more energy than FO plants, thermal evaporation is a less energy-efficient option.

Desalination in Australia

Large-scale seawater RO desalination plants have been constructed in five Australian states to supply municipal water. The cost of producing desalinated water in Australia ranges between $1 and $4 per kilolitre.

Large-scale Desalination Facilities in Australia			
Location	**Desalination Plant**	**Capacity (GL/year)**	**Completion Date**
Western Australia	Perth Seawater Desalination Plant (Kwinana)	45	2006
	Southern Seawater Desalination Plant (Binningup)	100	2012
Queensland	Gold Coast Desalination Plant (Tugun)	49	2009
South Australia	Adelaide Desalination Plant (Port Stanvac)	100	2012
Victoria	Victorian Desalination Plant (Wonthaggi)	150	2012
New South Wales	Sydney Desalination Plant (Kurnell)	90	2010

The Australian plants are closely monitored to ensure that there are no adverse effects on the environment. Offshore infrastructure is regularly inspected and the quality of the water entering and leaving the plants is continuously monitored, in real-time. Diffuser systems are also routinely monitored to ensure that they are performing as required. In Western Australia and Queensland the diffuser systems have become artificial reefs and support a wide array of marine life.

While the plants are powered by electricity from the grid, efforts have been made to offset the energy they use. Wind and solar farms were constructed simultaneously with the construction of the desalination plants, to increase the amount of renewable energy supplied to the electrical grid.

The Western Australian plants continuously supply water to Perth, while the operation of the other plants depends on the local demand and supply situation. The Queensland plant, for example, operates in a “hot standby” mode. It produces more water during floods, droughts or when conventional water treatment plants are offline. Other plants, including those in Sydney and Melbourne, have been used very infrequently since they were constructed.

The two desalination plants in Western Australia have the capacity to supply up to half of Perth’s water supply and the Kwinana plant could be expanded to meet future demand. The region has become drier over the past century, with rainfall runoff into dams declining by 90 per cent. Consequently, it needs to find alternative water supplies that are climate-independent. The city maintains other water supplies, including groundwater and dams, however, to better ensure that supply disruptions are minimised and operating costs are kept low.

Some commentators view Australia's desalination facilities as a costly financial mistake, however, as they were constructed at a time of prolonged water stress. Those water supply conditions have since improved and the desalination plants are viewed by some as unnecessary and costly burdens on public finances. The Sydney plant, for example, has not operated since it was damaged by a storm in 2015. Maintenance of the plant continues to cost the average household $85 per year, although it is not currently supplying them with water. Until recently, the Victorian plant was in a similar situation. The plant sat idle for four years after its completion in December 2012. As part of a new water agreement, the plant will supply water to existing reservoirs to help avoid a future water crisis. Annual water charges are expected to rise by $12 for each Melbourne household as a result of this policy, but the desalination plant does continue to provide an insurance policy for any shortfall in the supply of water.

The Australian experience with desalination has generally been positive. Environmental monitoring ensures that adverse environmental effects are minimised and promptly addressed if they occur. Given the cost of building and maintaining desalination infrastructure, however, assessing the need for desalination plants requires careful consideration. On the other hand, once the plant is built it provides an insurance policy for the cities and ensures that even in times of drought their water security remains robust.

Conclusion

Desalination could assist in reducing the global water supply challenge. Energy intensity, cost and the environmental effects of desalination plants are the main impediments to the adoption of the technology, but research and development efforts are being undertaken on each of those fronts. Alternative materials, such as graphene or other nanomaterials, could reduce the costs associated with RO desalination. Similarly, FO desalination could reduce the cost of purifying extremely saline or polluted water that cannot be processed by RO plants.

The Australian experience with desalination facilities shows that careful consideration should be given to the requirement for desalination over the long-term. It suggests that desalination should be considered as a last resort for many parts of the world, to be undertaken only when alternative options, such as accessing groundwater reserves or water recycling, have been considered. As a climate-independent source of water, however, desalination remains the best option for the most climate-sensitive parts of the world. Further research and development is likely to make it an increasingly attractive option.

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